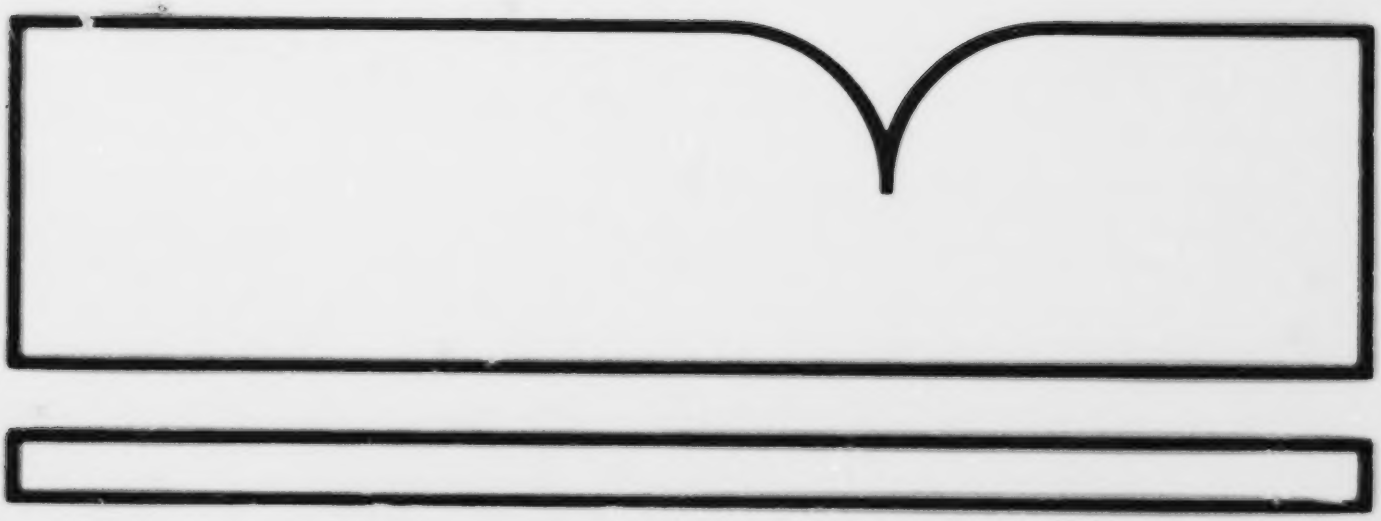
PB89-190821

Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites

(U.S.) Environmental Protection Agency
Washington, DC

Mar 89



U.S. Department of Commerce
National Technical Information Service
NTIS

PB89-190821

United States
Environmental Protection
Agency

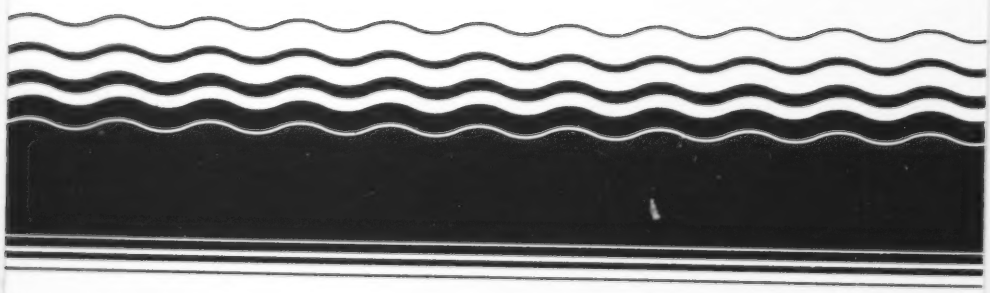
Office of Environmental Engineering
and Technology Demonstration
Washington DC 20460

Superfund

EPA/540/2-89/052 March 1989

EPA

Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites



REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/540/2-89/052
March 1989

Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites

Office of Environmental Engineering and Technology Demonstration
U.S. Environmental Protection Agency
Washington, DC 20460

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Table of Contents

Chapter		Page
	Introduction	1
	Acknowledgement	3
I.	Biological Treatment	5
	Activated Sludge	5
	Aerobic Treatment	5
	Anaerobic Treatment	5
	Bacteria	5
	Composting	6
	Enzyme Treatment	6
	Lagoons and Ponds	6
	Mycorrhizas	6
	Rotating Biological Contactor	6
	Trickling Filter	6
	White Rot Fungus	7
	Yeast Strains	7
II.	Chemical Treatment	8
	Chlorinolysis	8
	Dehalogenation	8
	Electrochemical Dehalogenation	8
	Electrolytic Oxidation	8
	Hydrolysis	8
	Ion Exchange	8
	Lignin Adsorption	8
	Neutralization	9
	Oxidation	9
	Polymerization	9
	Precipitation	9
	Reduction	10
	UV/Photolysis	10
III	Physical Treatment	11
	Component Separation	
	Air Flotation	11
	Centrifugation	11
	Filtration	11
	Belt Filter Press	11
	Chamber Pressure Filtration	11
	Granular Media Filtration	11
	Vacuum Filtration	11
	Gravity Separation	12
	In Situ Soil Extraction	12

Phase Separation
Air Stripping 13
Carbon Adsorption 13
Collidal Gas Aphrons 13
Distillation 13
Electrokinetics 13
Evaporation 13
Freeze Crystallization 14
Mechanical Soil Aeration 14
Metal Binding 14
Resin Adsorption 14
Reverse Osmosis 14
Solvent Extraction 14
Steam Stripping 15
Supercritical Extraction 15
Ultrafiltration 15

IV. Stabilization/Solidification/Encapsulation Treatment 16
Cement-based Fixation 16
Macro-Encapsulation, Overpacking, Thermoplastic and Thermosetting Techniques 16
Pozzolanic-based Fixation 16
Sorptive Clays 16
Vitrification 16

V. Thermal Treatment 17
Electric Reactor 17
Fixed Hearth 17
Fluidized Bed 17
Industrial Boiler 17
Industrial Kiln 17
Infrared Incineration 17
Liquid Injection 18
Molten Glass 18
Molten Salt 18
Multiple Hearth 18
Plasma Systems 18
Pure Oxygen Burner 18
Pyrolysis 18
Radio Frequency Thermal Heating 19
Rotary Kiln 19
Supercritical Water Oxidation 19
Wet Air Oxidation 19

References 21

Introduction

Over the past few years, it has become increasingly evident that land disposal of hazardous wastes is at least only a temporary solution for much of the wastes present at Superfund sites. The need for more long-term, permanent treatment solutions as alternatives to land disposal has been stressed by recent legislation such as the Hazardous and Solid Waste Amendments of the Resource Conservation and Recovery Act (RCRA) as well as the Superfund Amendments and Reauthorization Act (SARA) of 1986. SARA directs the U.S. Environmental Protection Agency to establish an "Alternative or Innovative Treatment Technology Research and Demonstration Program," to identify promising technologies, assist with their evaluation, and promote the use of these technologies at Superfund sites.

This *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites* addresses alternative technologies that can be used to treat wastes at Superfund sites. This guide is designed for use by EPA Regional Offices, States, remedial contractors, and others to aid in the identification of alternative technologies that have been or are currently being developed. The alternative technologies presented in this guidebook are organized according to the method of treatment. These treatment methods comprise the following five sections of the alternative technologies table:

Section I: Biological Treatment. A treatment process in which bacteria, fungi, and/or microorganisms are used to alter or destroy hazardous waste. Liquid and soil wastes that can be treated by this method may include toxic chlorinated and aromatic organic compounds. The process is highly sensitive to environmental conditions, including fluctuations in pH and temperature, and to changes in the concentrations of heavy metals and salts in the waste stream.

Section II: Chemical Treatment. A treatment process in which the hazardous waste is altered by a chemical reaction in order to destroy the hazardous component. Wastes that can be treated by this method include both organic and inorganic compounds without heavy metals. Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts.

Section III: Physical Treatment. A treatment process in which the hazardous waste is separated from its carrier by various physical methods such as adsorption, distillation, filtration, etc. Physical treatment is applicable to a wide variety of wastes but further treatment is usually required.

Section IV: Stabilization, Solidification, and Encapsulation Treatment. A treatment process which isolates hazardous wastes from the surrounding environment without destroying the hazardous constituents. The treatment objective is normally achieved by mixing the waste with an inorganic compound such as fly ash, lime, clay, etc., to form a chemically and mechanically stable solid. The treated waste generally has higher strength, lower permeability, and lower leachability than the untreated waste. Stabilization/solidification/encapsulation treatment is applicable primarily to inorganic wastes containing heavy metals. Organic compounds often interfere with the setting action of the solidifying agent. There is no guarantee of the effectiveness of this method over time due to a lack of data on long-term leachability studies. This type of treatment may be feasible for use at sites with limited space or in emergency actions to alter the form of the waste to a more easily transportable form.

Section V: Thermal Treatment. A treatment process involving the decomposition of hazardous waste by thermal means into less hazardous or nonhazardous components. When subjected to high temperatures (2500-3000°F), organic wastes decompose to similar, less toxic forms. Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide, nitrous oxides, and chlorine and bromine acid gases. Some thermal processes produce off-gases and ash that require further treatment or landfill disposal. Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds. One drawback of thermal treatment is the high cost involved.

The alternative technologies are listed alphabetically under the five treatment methods. Each technology entry provides information concerning the type(s) of wastes to which the technology can be applied. The table also presents limitations and special use considerations for the particular alternative treatment technology (i.e., particle size restrictions, water-content limitations, heavy-metals-content limitations, etc.). The phase of development of the technology is also included in the table. The three phases of development for the alternative treatment technologies included in this guidebook are defined as follows:

1) *Available Alternative Technology*: a technology that is fully proven and in routine commercial or private use.

2) *Innovative Alternative Technology*: a technology for which cost or performance information is incomplete, thus hindering routine use at hazardous waste sites. An innovative alternative technology requires full-scale field testing before it is considered proven and available for routine use.

3) *Emerging Alternative Technology*: a technology that has not yet successfully passed laboratory or pilot-scale testing.

The table indicates whether or not the technology is transportable for use on site, and references are listed in the last column of the table to direct the reader to more detailed sources of information on the technology.

This guidebook is designed for use in the field as a guide to alternative technologies; it is not intended to serve as a reference source to identify the **best** available technology for treating a particular hazardous waste at a specific site. The mention of trade names or commercial products does not constitute their endorsement or recommendation for use by the U.S. Environmental Protection Agency.

Requests for copies of this document should be directed to the ORD Publications Office, Center for Environmental Research Information, Cincinnati, OH 45268, (513) 569-7562.

Acknowledgements

This guidebook was prepared by the Office of Environmental Engineering and Technology Demonstration of the U.S. Environmental Protection Agency (EPA) with coordination conducted by Alfred A. Galli (Chief, Air and Energy Branch). The production of this document was facilitated by Beverly J. Campbell, Technical Resources, Inc., Rockville, MD.

Individuals and organizations throughout EPA contributed draft material that formed the basis for much of this document. Without their contribution and the special assistance of John F. Martin and Naomi P. Barkley (Risk Reduction Engineering Laboratory in Cincinnati), the production of this guide would not have been possible.

Preceding page blank

I. BIOLOGICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Activated Sludge	Soluble organics in dilute aqueous waste streams (< 1% suspended solids)	• BOD < 11,000 ppm • Requires low concentrations of heavy metals, PCBs, pesticides, oil, and grease • Output sludge contains heavy metals and refractory organics which require further treatment	A	X	1, 35, 58
Aerobic Treatment (sequential batch reactor, fluidized bed, fixed film fluidized bed with/without activated carbon, aerated biofilm reactor, membrane reactor)	Aqueous waste with low levels of nonhalogenated organics and certain halogenated organics (i.e., phenols, formaldehyde, PCP)	• BOD < 10,000 ppm • Requires consistent, stable operating conditions	A	X	1, 2, 3, 5, 59
Anaerobic Treatment (fluidized bed, fixed film fluidized bed with/without activated carbon)	Aqueous slurry with low to moderate levels of nonchlorinated organic compounds containing < 7% solids	• Requires consistent, stable operating conditions • Unsuitable for oil and grease, aromatics, and long chain hydrocarbons • Output sludge requires incineration	A	X	1, 2, 3, 5, 62, 66
Bacteria	PCBs and various other organic compounds in soils (i.e., 2,4,5-T and 2,4-D)	• May involve genetic engineering • Natural adaptation	A	X	6, 42, 54, 61, 62, 64, 65, 66

[1]PHASE = Phase of Development, A = Available, I = Innovative, E = Emerging [2]MOBILE = Transportable

I. BIOLOGICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Composting	Aqueous sludge with < 50% solids, nonchlorinated hydrocarbons, high organic wastes including oils, tars, and industrial processing sludges.	• Requires nutrient supplementations. • Output sludge contains heavy metals.	A	X	81, 82, 83, 84
Enzyme Treatment	Soluble organics in dilute aqueous waste streams.	• Requires stable influent concentration.	E	X	5, 41, 60, 61, 62, 65
Lagoons and Ponds	Industrial wastewater, organics with slow biodegradation potential, soluble organics in dilute aqueous waste streams.	• Requires large area. • Unsuitable for solids. • Requires a temperate climate. • Output sludge contains heavy metals and refractory organics which require further treatment.	A		63, 66
Mycorrhizas	Soil-entrained hazardous waste constituents.		E	X	77
Rotating Biological Contactor	Biodegradable dilute aqueous organic waste including solvents and halogenated organics.	• Limited to low concentrations of heavy metals and concentrated refractory organics. • Unsuitable for sludges or solids.	A	X	1, 23, 24, 25, 40
Trickling Filter	Soluble organics in dilute aqueous waste streams with < 1% suspended solids including solvents and halogenated organics.	• BOD < 5,000 ppm. • Output sludge contains heavy metals and refractory organics which require further treatment.	A	X	85

[1]PHASE - Phase of Development; A = Available, I = Innovative, E = Emerging [2]MOBILE = Transportable

I. BIOLOGICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
White Rot Fungus *(Phanerochaete chrysosporium)*	Toxic or refractory halogenated organics in soil (i.e., 2,3,7,8-TCDD, DDT, mirex, lindane, hexachlorobenzene).		E	X	1, 43, 56, 57, 60, 61, 62, 66, 68
Yeast Strains	Halogenated organics.	• Involves genetic engineering	E	X	60, 61, 66

[1]PHASE - Phase of Development, A = Available, I = Innovative, E = Emerging [2]MOBILE = Transportable

II. CHEMICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Chlorinolysis	Concentrated liquid chlorinated organic waste streams with low concentrations of sulfur and oxygen.	• Unsuitable for solids and tars. • Unsuitable for benzene and aromatics. • Output carbon tetrachloride can be recovered.	I		3, 50
Dehalogenation (including use of the Alkali Metal Polyethylene Glycol Reagent - APEG)	Halogenated organics in soils and sludges that are partially dehydrated (i.e., PCBs, dioxins).	• Requires heat and excess reagent.	I	X	1, 2, 47
Electrochemical Dehalogenation	Halogenated organics (i.e., PCBs).	• Not known.	E		22, 78
Electrolytic Oxidation	High concentration cyanide (10%) and metals wastes.	• Suitable for low solid content waste.	A		1, 2
Hydrolysis	Solids, soils, sludges, slurries, or liquids contaminated with organic compounds.	• Requires careful handling of strong acids and alkalines. • Reaction is performed at high temperatures and pressure requiring close monitoring.	A	X	1, 2, 3
Ion Exchange	Aqueous organic or inorganic waste streams, principally metals.	• Suitable for liquid waste only.	A	X	1, 2, 5, 35
Lignin Adsorption	Aqueous organic or inorganic waste streams.	• Not known.	E	X	67

[1]PHASE - Phase of Development, A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

II. CHEMICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Neutralization	Corrosive liquid wastes, both acids and bases.	• Unsuitable for sludges and solids. • Requires corrosion resistant equipment.	A	X	1, 2, 3, 35
Oxidation (chlorination, ozonation, hydrogen peroxide, potassium permanganate, chlorine dioxide, hypochlorites)	Dilute aqueous waste (< 1% waste) containing organic/inorganic compounds.	• Requires controlled reaction conditions. • Suitable for liquids and sludges only.	A	X	1, 2, 3, 5, 35, 50
Polymerization	Organic compounds such as aromatics, aliphatics, and oxygenated monomers.	• Application is limited to spills.	I	X	1, 2, 5
Precipitation	Aqueous organic and inorganic waste containing metals.	• Requires optimization of the reaction pH for the specific mix of metals present. • Output sludge requires further treatment. • Cross-reactivity may occur for mixed-metals content waste. • Unsuitable for sludges, tars, and slurries.	A	X	1, 2, 5, 35, 69, 70, 71

[1]PHASE - Phase of Development, A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

II. CHEMICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Reduction (Sulfur dioxide, sodium boro-hydride sulfite salts, ruthenium tetraoxide)	Dilute aqueous waste stream containing inorganic compounds, especially metals (< 1% heavy metal concentration).	• Applicable to inorganic waste only. • Suitable for liquid waste only.	I	X	1, 2, 3, 5, 35, 50
UV/Photolysis	Liquid waste containing dioxins.	• Suitable for liquids only.	E	X	1, 2, 5, 50

[1]PHASE - Phase of Development; A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

III. PHYSICAL TREATMENT TECHNOLOGIES (COMPONENT SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Air Flotation (dissolved or induced)	Liquid waste containing oils or light suspended solids.	• Liquid effluent may require further treatment.	A	X	1
Centrifugation (bowl, basket, disk)	Organic/inorganic liquids, slurries, and sludges containing suspended or dissolved solids or liquids where one component is nonvolatile. For example, wastewater sludge, wastes containing immiscible liquids, or wastes containing three distinct phases.	• Unsuitable for tars, solids, dry powders, or gases. • Not applicable for small size or low density particles.	A	X	1, 2, 7, 8, 9
FILTRATION:					
Belt Filter Press	Biological and industrial sludges.	• Filter cake may require further treatment.	A	X	1, 2, 8, 9, 11
Chamber Pressure Filtration (pressure leaf, tube element, plate and frame, horizontal plate)	Wastewater sludges, or sludges with a flocculated or adhesive nature.	• Dewatering technology. • Unsuitable for sticky or gelatinous sludges.	A	X	1, 8, 9, 11
Granular Media Filtration	Liquid waste containing suspended solids and/or oils.	• Requires pretreatment for suspended solids with concentration < 100 mg/l. • Requires frequent backwashing.	A	X	1, 2, 3, 9, 11, 35
Vacuum Filtration (fixed media, rotary drum)	Organic or inorganic chemical sludges, metals, and cyanides bound up in hydroxide sludges.	• Dewatering technology. • Unsuitable for sticky or gelatinous sludges.	A	X	2

[1]PHASE - Phase of Development; A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

III. PHYSICAL TREATMENT TECHNOLOGIES (COMPONENT SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Gravity Separation (coagulation, flocculation, sedimentation)	Liquid waste containing settleable suspended solids, oils, and/or grease.	• Liquid effluent may require further treatment. • Unsuitable for heavy slurries, sludges, or tars.	A	X	1, 35
***In Situ* Soil Extraction**	Soils with low levels of organics or inorganics/metals contamination.	• Unsuitable for dry or organic-rich soils.	E	X	1, 2, 5

[1]PHASE - Phase of Development; A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

III. PHYSICAL TREATMENT TECHNOLOGIES (PHASE SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Air Stripping	Aqueous and adsorbed organic and inorganic wastes with relatively high volatility and low water solubility such as chlorinated organics, aromatics, and ammonia	• Limited to VOC concentration < 100 ppm. • Suspended solids may clog tower.	A	X	1, 2, 35, 50
Carbon Adsorption	Aqueous organic wastes (containing < 1% total organics and < 50 ppm solids) with high molecular weight and boiling point, and low water solubility, polarity, and ionization.	• Unsuitable for metals. • Unsuitable for oil and grease.	A	X	1, 2, 5, 28, 29, 30, 31, 32, 35, 50
Colloidal Gas Aphrons (CGAs) (enhances air stripping and biodegradation)	Soils contaminated with phenols, phthalate esters, aromatic hydrocarbons, aliphatic hydrocarbons, chlorinated hydrocarbons, amines, and alcohols.	• Hydraulic conductivity of the soil must be > 10^{-4} cm/sec.	E	X	79, 80
Distillation	Liquid organic mixtures with low viscosity that can be separated due to molecular weight/volatility differences.	• Unsuitable for thick polymeric materials, slurries, sludges, or tars.	A	X	1, 2
Electrokinetics	Soils contaminated with organic or inorganic waste.	• Soil matrix must be relatively permeable and saturated.	I		1, 38, 49
Evaporation	Organic/inorganic liquid solvents contaminated with nonvolatile impurities (i.e., oils, grease, paint solvents, polymeric resins).	• Liquids must be volatile. • Unsuitable for tars, solids, dry powders, or gases. • Energy-intensive process.	A	X	1, 2

[1]PHASE - Phase of Development, A = Available, I = Innovative, E = Emerging [2]MOBILE = Transportable

III. PHYSICAL TREATMENT TECHNOLOGIES (PHASE SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Freeze Crystallization	Dilute aqueous organic/inorganic waste solutions containing < 10% total dissolved solids.	• Unsuitable for foamy, viscous, or high solid content waste streams.	E	X	86, 87, 88
Mechnical Soil Aeration	Volatile organics in sludge and soil.	• Effluent may require further treatment.	A	X	3
Metal Binding	Metal-contaminated aqueous waste streams, leachate, or groundwater.	• Limited to metal concentrations between 500-1000 ppm.	E		1, 5, 10, 12, 21
Resin Adsorption	Aqueous waste streams containing soluble organics, particularly phenols and explosive materials.	• Limited to low concentrations of organics (< 8%) and suspended solids (< 50 ppm).	A		35
Reverse Osmosis	Aqueous waste streams containing < 400 ppm heavy metals, high molecular weight organics, and dissolved gases.	• Unsuitable for oxidants. • Requires controlled pH, low concentration of suspended solids.	I	X	1, 35, 73
Solvent Extraction	Aqueous stream contaminated with single- or multi-component dissolved organic wastes. Sludge contaminated with oils, toxic organics, and heavy metals.	• Extracting solvent must be immiscible in the liquid and differ in density so gravity separation is possible. • Suitable for sludges containing < 20 wt % oil/organics and < 20 wt % solids.	A, I	X	3, 17, 18, 20, 26, 50

[1]PHASE - Phase of Development, A = Available, I = Innovative, E = Emerging [2]MOBILE = Transportable

III. PHYSICAL TREATMENT TECHNOLOGIES (PHASE SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Steam Stripping	Aqueous solutions of volatile organics.	• Effluent may require further treatment. • Suitable for waste streams with low metal concentration.	A	X	1, 2, 19, 33, 34
Supercritical Extraction	Sludge, solids, or liquids contaminated with organics.	• Effluent may require further treatment.	E	X	1, 46, 51, 52
Ultrafiltration	Removes oils, metals, and proteins from aqueous solutions with dissolved organics, emulsions, and colloidal particles.	• Limited to low concentrations of suspended solids.	A	X	74, 75, 76

[1]PHASE - Phase of Development; A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

IV. STABILIZATION/SOLIDIFICATION/ENCAPSULATION TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Cement-based Fixation	Treated sludges and soils containing metal cations, radioactive wastes, and solid organics (i.e., plastics, resins, tars).	• Long term stability/leachability is unknown. • Lignite, silt, and clay increase setting time. • Dissolved sulfate salts, borates, and arsenates must be limited.	A	X	1, 2, 3, 4, 27, 35, 48
Macro-Encapsulation, Overpacking, Thermoplastic and Thermosetting Techniques	Chemically or mechanically stabilized organic, inorganic, and radioactive wastes.	• Encapsulating matrix must be compatible with waste. • Long term leachability unknown, therefore, waste storage must be considered. • Requires specialized equipment.	A	X	2, 3, 4, 27, 35
Pozzolanic-based Fixation (fly ash, lime based)	Treated sludges and soils containing heavy metals, waste oils, solvents, and low level radioactive waste.	• Borates, sulfates, and carbohydrates interfere with the process. • Long term stability/leachability is unknown.	A	X	1, 2, 3, 4, 27, 48
Sorptive Clays (treated, chemically modified)	Halogenated organic compounds and heavy metals.	• Long term leaching is a problem, therefore, waste storage must be considered.	I	X	1, 3, 4, 27, 35, 72
Vitrification	Soils contaminated with organic, inorganic, and radioactive wastes.	• Limited to soils with high silica content.	A, I	X	1, 2, 3, 27, 35, 44, 50

[1]PHASE - Phase of Development; A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

V. THERMAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Electric Reactor	Soil contaminated with solid and liquid organics and inorganics.	• Contaminated soil must be finely divided and dry.	I	X	1, 2, 13, 16
Fixed Hearth	Bulky solids, liquids, and sludges.	• Particle size must be large enough not to fall through grate.	A		14, 15
Fluidized Bed	Organic solids, liquids, and sludges.	• Requires low water and inert solid content.	A	X	1, 2, 3, 14, 15, 35
Industrial Boiler	Granulated solids, liquids, and sludges.	• Requires low chlorine and sulfur content. • Ash content clogs system. • Small particle size.	A		1, 2, 13, 14, 36
Industrial Kiln	Spent pot lining, nonhalogenated oils, and PCB-contaminated liquids and sludge.	• Requires low chlorine and sulfur content.	A		1, 2, 14
Infrared Incineration	Soils, solids, and sludges contaminated with chlorinated organic compounds (i.e., PCBs, dioxins, explosives).	• Primarily for solid organic waste. • Heavy metals are not fixed in ash.	A	X	1, 2

[1]PHASE - Phase of Development; A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

V. THERMAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Liquid Injection	Pumpable liquid organic waste.	• Unsuitable for inorganic content and heavy metal content wastes. • Chlorinated solvents cause accelerated corrosion rates.	A	X	1, 2, 3, 14, 35
Molten Glass	Organic solids, liquids, gases, sludges (i.e., plastics, PCBs, asphalt, pesticides).	• Sodium sulfates must be limited to < 1% content. • Inappropriate for soils and high ash content waste.	I		1, 2, 16
Molten Salt	Low ash content waste, low water content liquid, or solid waste.	• Corrosion problems. • Requires frequent bed replacement.	I	X	1, 2, 16
Multiple Hearth	Granulated solids, sludges, tars, liquids, and gaseous combustible waste.	• Water, salt, and metal content must be limited. • Particle size must be small enough to pass through injector nozzles. • Not recommended for hazardous wastes.	A		2, 3, 35
Plasma Systems	Liquid organic wastes (i.e., pesticides, dioxins, PCBs, halogenated organics).	• Liquids only.		X	1, 2, 13, 16, 37
Pure Oxygen Burner	Liquid wastes which require high temperatures for destruction or have low heating values.	• Requires specially engineered nozzles to atomize the liquid waste.		X	16
Pyrolysis	Viscous liquids, sludges, solids, high ash content materials, salts and metals, and halogenated waste.	• Requires homogeneous waste input. • Metals and salts in the residue can be leachable.		X	1, 2, 16, 50

[1]PHASE - Phase of Development; A = Available, I = Innovative, E = Emerging [2]MOBILE = Transportable

V. THERMAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Radio Frequency Thermal Heating	Volatile, low boiling point, or easily decomposed organic compounds in soil.	• Not known.	I	X	2, 16, 50
Rotary Kiln	Solid, liquid, or gaseous organic waste.	• Containerized wastes are difficult to handle. • High inorganic salt or heavy metal content wastes require special consideration. • Fine particulate matter must be limited.	A	X	1, 2, 13, 14, 15, 35, 45
Supercritical Water Oxidation	Aqueous organic solution/slurry or mixed organic/inorganic waste.	• Now known.	I	X	1, 16, 39, 50
Wet Air Oxidation	Aqueous waste streams (< 5%) with dissolved or suspended volatile organic substances.	• Unsuitable for solids, viscous liquids, or highly halogenated organic compounds. • Not economical for dilute or concentrated waste.	A	X	1, 16, 50

[1]PHASE - Phase of Development; A = Available; I = Innovative; E = Emerging [2]MOBILE = Transportable

REFERENCES

1. A Compendium of Technologies Used in the Treatment of Hazardous Wastes; September 1987; EPA/625/8-87/014; ORD.

2. Treatment Technology Briefs: Alternatives to Hazardous Waste Landfills; July 1986; EPA/600/8-86/017; PB87-110680.

3. Systems to Accelerate In Situ Stabilization of Waste Deposits; September 1986; EPA/540/2-86/002; PB87-112306.

4. Handbook for Stabilization/Solidification of Hazardous Wastes; June 1986; EPA/540/2-86/001; PB87-116745.

5. Review of In-Place Treatment Techniques for Contaminated Surface Soils — Vol. 1: Technical Evaluation; September 1984; EPA/540/2-84/003a; PB85-124881.

6. Leachate Plume Management, November 1985; EPA/540/2-85/004; PB86-122330.

7. Centrifuges: A Guide to Performance Evaluation; 1980; Equipment Testing Procedures Committee/American Institute of Chemical Engineers.

8. Filtration and Separation/Filtration Society (1980 thru present issues); Upland Press (Great Britain).

9. Filters and Filtration Handbook; 1981; Gulf Publishing Company; Warring, R.

10. Recent Progress in Biohydrometallurgy; 1983; Association Mineraria Sarda (Rome); Rossi, G., and A. Torma.

11. Filtration; 1961; Reinhold Publishing Corp., N.Y.; Dickey, G.

12. New Technology for Closed-Loop Source Reduction of Toxic Heavy Metal Wastes in Nuclear and Metal Finishing Industries; DeVoe — Holbein Technology, DeVoe, I., B. Holbein, et al.

13. An Overview of Pilot-Scale Research in Hazardous Waste Thermal Destruction; 1985; Proceedings: International Conference on New Frontiers for Hazardous Waste Management; Lee, C., and G. Huffman; EPA/600/8-87/018F; PB86-183035.

14. Handbook: Permit Writer's Guide to Test Burn Data in Hazardous Waste Incineration; September 1986; EPA/625/6-86/012; ORD.

15. Incineration of Hazardous Waste: A Critical Review; May 1987; Journal of the Air Pollution Control Association — Vol. 37, No. 5; Oppelt, E.

16. Innovative Thermal Hazardous Waste Treatment Processes; June 1985; EPA/600/S2-85/049; PB85-192847.

17. Evaluation and Development of Polychlorinated Biphenyl Removal Processes; February 1982; Union Carbide Corporation/Nuclear Division; Napier, J., M. Travaglini, G. Laggis, and M. Makarewicz; Report Y/DZ-1.

Preceding page blank

18. Liquid Extraction; 1985; Journal of Hazardous Materials; Elsevier Science Publishing B. V. Amsterdam; Alders, L.

19. Best Demonstrated Available Technology (BDAT) Document for F001-F005 Spent Solvents; November 1986; EPA/530-SW-86-056; OSW.

20. Mobile System for Extracting Spilled Hazardous Materials from Excavated Soils; 1984; EPA/DF-84/052; PB84-221795/REB.

21. Proceedings: Massachusetts Hazardous Waste Reduction Conference, pg. 66; October 18, 1984; Massachusetts Department of Environmental Management.

22. An Electrochemical Process for Decontaminating PCB-containing Transfer Coolants; October 1985, Electric Power Research Institute (EPRI); Massey, M., and F. Walsh; CS/EA/EL-4480.

23. Stringfellow Leachate Treatment With RBC; February 1988; Environmental Progress 7; No. 1; Opatken, E., H. Howard, and J. Bond.

24. An Alternative RBC Design — Second Order Kinetics; February 1986; Environmental Progress 5; No. 1; Opatken, E.

25. Design Information on Rotating Biological Contactors, June 1984; U.S. EPA, HWERL; EPA 600/2-84/106; PB84-199561.

26. EPA Project Summary Mobile System for Extracting Spilled Hazardous Materials from Excavated Soils; 1984; Journal of Hazardous Materials; Vol. 9, pp. 241-252; Scholz, R., and J. Milonowski.

27. A Review of Solidification/Stabilization Technology; 1987; Journal of Hazardous Materials 14; Elsevier Science Publishing B. V. Amsterdam; Wiles, C.

28. Adsorption of Biochemically Resistant Materials from Solution. 1.; 1964; Public Health Service Publication No. 999-WP-11; Morris, J., and W. Weber.

29. Adsorption of Biochemically Resistant Materials from Solution. 2.; 1966; Public Health Service Publication No. 999-WP-33; Morris, J., and W. Weber.

30. Physiochemical Processes for Water Quality Control; 1972; Wiley — Interscience; Weber, W.

31. Control of Organic Substances in Water and Wastewater (pg. 203, article entitled "Removal of Organic Substances from Municipal Wastewaters by Physiochemical Processes"); April 1983; EPA-600/8-83-011; PB86-94184744.

32. Evolution of a Technology; 1984; Journal of Environmental Engineering; Vol. 110, No. 5, pp. 899-917.

33. Unit Operations for Treatment of Hazardous Industrial Wastes; 1978; Noyes Data Corporation; De Renzo, D., Editor.

34. Equilibrium — Stage Separation Operations in Chemical Engineering; 1981; John Wiley & Sons, Inc.; Henley, Ernest, and J. Seader.

35. Handbook: Remedial Action at Waste Disposal Sites (Revised); October 1985; EPA/625/6-85/006; PB82-239054.

36. Nonsteady-state Testing of Industrial Boilers Burning Hazardous Wastes; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

37. Waste Destruction by Plasma Arc Pyrolysis; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

38. Evaluating Electro-Kinetics as a Remedial Action Technique; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

39. The destruction of Hazardous Organic Waste Materials Using MODAR Oxidation Process; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

40. Biological Treatment of Hazardous Aqueous Wastes; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

41. Stabilization of Enzymes Used to Degrade Pesticides; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

42. Bacterial Treatment of PCB-Contaminated Soils: Prospects for the Application of Recombinant DNA Technology; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/18F; ORD.

43. White Rot Fungus Detoxification Research: Status and Directions; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

44. *In Situ* Vitrification — An Innovative Thermal Treatment Technology; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

45. Pilot-Scale Incineration of a Dioxin-Containing Material; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

46. Supercritical Fluid Extraction and Catalytic Oxidation of Toxic Organics from Soils; September 1987; Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

47. Chemical Destruction of Chlorinated Dioxins and Furans; September 1987; Second International Conference on New Frontiers for Hazardous Waste Managment; EPA/600/9-87/018F; ORD.

48. An Assessment of Materials that Interfere with Stabilization/Solidification Processes; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

49. Electro-Decontamination of Chrome-Contaminated Soils; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

50. Technical/Economic Assessment of Selected PCB Decontamination Processes; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

51. Supercritical Solvent Extraction; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

52. Supercritical Fluid Extraction from Catalytic Oxidation of Toxic Organics from Soils; July 1987; Land Disposal Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

53. Microbial Degradation of Synthetic Chlorinated Compounds; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

54. Bacterial Oxidation of Polychlorinated Biphenyls; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

55. Engineering P450 Genes in Yeast; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

56. Biodegradation of Organopollutants by *Phanerochaete Chrysosporium*: Practical Considerations; July 1987; Land disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

57. Growth of the White-Rot Fungus *Phanerochaete Chrysosporium* in Soil; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

58. Biological Treatment of Selected Aqueous Organic Hazardous Wastes; July 1987; Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Thirteenth Annual Research Symposium; EPA/600/9-87/015; PB87-233151.

59. Treatment of Toxic Wastewaters by Powdered Activated Carbon; September 1987; pg. 170; Proceedings of Second International Conference on New Frontiers for Hazardous Waste Management; EPA/600/9-87/018F; ORD.

60. Microbial Decomposition of Chlorinated Aromatic Compounds; September 1986; EPA/600/2-86/090; ORD.

61. Microbial Degradation of Xenobiotics and Recalcitrant Compounds; 1981; Academic Press; edited by Leisinger, T., A. Cook, R. Hutter, and J. Nuesch.

62. Microbial Decomposition of Organic Compounds; 1984; Marcel Dekker, Inc.; edited by Gibson, D.

63. Biodegradation Techniques for Industrial Organic Wastes; 1980; Noyes Data Corporation; edited by DeRenzo, D.

64. Microbial Degradation of Halogenated Compounds; April 1985; Science - Vol. 228, No. 4696, pp. 135-142; Ghosal, D., I. You, D. Chatterjee, and A. Chakrabarty.

65. Biodegradation of Chemicals of Environmental Concern; January 1981; Science - Vol. 211, pp. 132-138; Alexander, M.

66. Microbial Removal of Hazardous Organic Compounds; 1982; Environmental Science Technology, Vol. 16, No. 3, pp. 170A-183A; Kobayashi, H., and B. Rittmann.

67. An Evaluation of Pristine Lignin for Hazardous Waste Treatment; August 1987; O'Neil, D., C. Newman, E. Chian, and H. Gao; EPA/600/2-87/037; PB87-191664.

68. Biodegradation of Halogenated Hydrocarbons; Environmental Research Brief; June 1987; Aust, S., and J. Bumpus; EPA/600/M-87/012; ORD.

69. Selective Iron Removal from Process Solutions by Phosphate Precipitation; 1986; Iron Control in Hydrometallurgy; Chapter 23; John Wiley and Sons; Dahnke, D., L. Twidwell, and R. Robins.

70. Metal Value Recovery from Metal Hydroxide Sludges; February 1986;Twidwell, L. G.; EPA/2-85/128; PB86-157294.

71. Metal Value Recovery from Metal Hydroxide Sludges: Removal of Iron and Recovery of Chromium; February 1988; Twidwell, L. G., and D.R. Dahnke; EPA/600/2-88/019; PB88-176078.

72. Clay-Organic Complexes as Adsorbents for Phenols and Chlorophenols; 1986; Clay and Clay Minerals; Vol. 34; pp. 581-585; Mortland, M., S. Shaobai, and S. Boyd.

73. Separation of Dilute Hazardous Organics by Low Pressure Composite Membranes; July 1987; Bhattacharyya, D., T. Barranger, M. Jevtitch, and S. Greenleaf; EPA/600/2-87/053; PB87-214870.

74. Ultrafiltration; Advances in Separation and Purification; 1986; John Wiley and Sons; Michaels, A.

75. Application of Ultrafiltration to the Concentration and Separation of Solutes of Low Molecular Weight; 1980; J. Membrane Science; 6.; pp 71-82.

76. Ultrafiltration Handbook; 1986; Technomic Publishing Co.; Cheryan, M.

77. The Influence of the Rhizosphere on Crop Producitivity; 1986; Advances in Microbial Ecology, Volume 9; pp. 187-244; Plenum Press, New York; Marshall, K. (editor); Whipps, J., and J. Lynch.

78. An Electrochemical Process for Decontaminating PCB-Containing Transformer Coolants; October 1985; EPRI Conference; Massey, M., and F. Walsh; to order contact: EPRI Research Report Center, P.O. Box 50490, Palo Alto, CA 94303; (415) 965-4081

79. *In Situ* Biological Oxidation of Hazardous Organics; May 1984; Environmental Progress, Vol. 3, No. 4, pp103-107.

80. Use of Colloidal Gas Aphrons for *In Situ* Biodegradation of Contaminated Groundwater; Land Disposal, Remedial Action, Incineration, and Treatment of Hazardous Waste: Proceedings of the Fourteenth Annual Research Symposium; EPA/600/9-88/021.

81. Waste Treatment Composting as a Controlled System; Finstein, M., F. Miller, and P. Strom; Biotechnology, Vol. 8.

82. Analysis of EPA Guidance on Composting Sludges, Parts I to IV; Finstein, M., F. Miller, J. Hogan, and P. Strom; Biocycle, Jan. - April 1987.

83. Liquid Waste Composting; Patterson, J., and J. Short; March 1985; EPA/600/2-85/005; PB85-160406/AS.

84. Microbial Activity in Composting Municipal Sewage Sludge; Vestal, J., and V. McKinley; May 1986; EPA/600/2-86/025; PB86-166014/AS.

85. Trickling Filter/Solids Contact Process: Full-Scale Studies; Matasci, R., A. Benedict, and D. Parker; May 1986; EPA/600/2-86/046; PB86-183100/AS.

86. Recent Applications of Freeze Crystallization to Preferential Pollutant Removal and Reuse; April 1988; Heist, J.; Presented at Hazardous Waste Treatment Technologies, Government Institutes, Inc.; Washington DC.

87. CPI Warm Up to Freeze Concentration; Chowdhury, J.; Chemical Engineering; April 25, 1988, p. 24.

88. Sunflower Army Ammunition Plant: Freeze Crystallization Test Report and Wastewater Management Recommendation; March 1986; Technical Report 86-102, Chemical Waste Management, Inc.; Riverdale, IL 60627.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989 — 1553/87086